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Optimizing GPON Performance

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Abstract **—** With the current interest in green technologies, many government organizations such as the military and national laboratories are deploying or considering deploying energy efficient technologies. Gigabit Passive Optical Network (GPON) is an access layer network technology which, when properly deployed, offers the potential for significant energy savings and reduced operational expenses. GPON can operate at much greater distances than legacy copper-based network technologies such as an access layer switch or DSL and deliver higher bandwidth. Because GPON is significantly different than many legacy networking technologies, performance can sometimes become an issue when GPON is used to replace those technologies. This paper discusses GPON performance. It then presents laboratory performance test results of GPON equipment. It then uses these results to make recommendations on how to optimize GPON performance for data, video, and VoIP. GPON energy consumption is also tested and the results analyzed.

Keywords **—** *GPON, green technology, triple play, video, VoIP*

I. Introduction

GPON is an access network technology which is becoming more popular for several reasons. It is an energy efficient technology. It also can deliver more bandwidth over a longer range than legacy copper-based technologies such as an access layer switch or DSL due to the use of single mode optical fiber. However, GPON has different performance characteristics than many of these legacy network technologies. GPON as defined by the ITU-T G.984 specifications has a capacity of 2.488 Gbps in the downstream direction. Traffic in the downstream direction is broadcast to all users on the GPON port. GPON has a capacity of 1.244 Gbps in the upstream direction. The method used for upstream transmission is Time Division Multiple Access (TDMA). Although that sounds simple enough, it has important implications which this paper explores.

This paper presents the results of laboratory tests on GPON equipment. Results are presented for upstream, downstream, and bidirectional tests; GPON port to GPON port tests; and Multiport ONT tests. Test results showing the importance of Quality of Service for VoIP and video are also presented. The paper uses the test results to make recommendations on how to optimize GPON performance. It also discusses where GPON is a good technology to deploy and where it is not. Because GPON is touted as a green technology, energy consumption is also tested and the results analyzed.

II. GPON Performance

A basic GPON configuration is illustrated in Figure 1. The Optical Line Terminal (OLT) has one or more GPON modules which can have several GPON ports. A GPON port is connected to an optical splitter via single mode fiber. The splitter outputs are connected to the Optical Network Terminal (ONT) via single mode fiber. The ONT can have one or more 10/100/1000 Ethernet ports.

With 2.488 Gbps available for downstream traffic, using a 1x32 splitter would allow each ONT 77,750 Mbps if a Constant Bit Rate (CBR) traffic profile was applied to all of the ONT ports. The upstream rate 1.244 Gbps would allow each ONT 38,875 Mbps if a CBR traffic profile was applied to the ONT ports. This technique might be useful in some instances, such as a subscriber paying for a fixed bandwidth from an ISP. In an enterprise environment, higher bandwidth to the user is delivered by using an Unspecified Bit Rate traffic profile which allows the user to use as much bandwidth from what is available on the GPON port. To ensure fairness amongst ONTs on a GPON port and also maximize total throughput, GPON uses a Dynamic Bandwidth Algorithm (DBA). The DBA used on an OLT is not directly configurable by the GPON administrator. However, there are methods of influencing it which will be discussed later.

The OLT can have several 1 and/or 10 Gbps uplinks which connect to a router. Although not a GPON component, the router can affect the performance of a GPON deployment. It should also be noted that the host hardware, applications, and any networks in between will also affect the perceived performance of GPON.

III. GPON Performance Testing

The Introduction section covered the GPON performance specifications. Before deploying GPON, a much more detailed analysis and understanding of GPON performance should be performed. One of the best ways to acquire this knowledge is by laboratory testing.

Using a controlled laboratory environment, GPON equipment can be thoroughly tested and the results analyzed. For this paper, the GPON equipment is from Tellabs. The testing equipment is from Spirent. The equipment used is now described.

A. Tellabs GPON Equipment

Tellabs offers a full line of GPON equipment depending upon the capacity required. The equipment used for the tests was the following:

Tellabs 1150 Multiservice Access Platform (MSAP) - This is the OLT. It consists of the 1150 chassis and various modules which are inserted into the chassis. The 1150 MSAP supports up to 16 GPON QOIU7A modules. Each module has 4 GPON ports. Therefore, the 1150 MSAP can support 64 GPON ports. Each GPON port can support up to 32 ONTs. This allows the 1150 MSAP to support up to 2048 ONTs. The 1150 MSAP can have up to a 400 Gbps switching fabric capacity. Also, it can have 4 uplinks which operate at 10 Gbps and 8 uplinks which operate at 1 Gbps depending upon the configuration.

Tellabs ONT709 - This ONT has four Ethernet ports providing 10/100/1000 Base-T connectivity. The ONT709 is compliant to ITU-T G.984 recommendations. The Tellabs hardware and software used is listed in Table I.

B. Spirent TestCenter Equipment

The Spirent TestCenter is a testing platform from Spirent Communications. The Spirent TestCenter consists of a chassis and various test modules such as multi-port 1 Gigabit Ethernet (used) and 10 Gigabit Ethernet modules (not used) and testing software. The Spirent TestCenter hardware and software used in these tests are listed in Table II.

C. Other Network Equipment

Passive Optical Splitter - Each GPON port connects to a single strand of single-mode fiber. This fiber connects to a passive optical splitter. Passive optical splitters come in various sizes or split ratios. Typical sizes are 1x2, 1x4, 1x16, and 1x32. All testing performed in this paper used 1x16 passive optical splitters. Actual production deployments will most likely use 1x32 passive optical splitters. It should be noted that splitters are passive devices. Thus 4 active ONTs on a 16 port splitter would have the same performance as 4 active ONTs on a 32 port splitter. The passive optical splitter outputs connect to the ONT709s. The higher the splitter ratio, the less distance the ONTs can be from the GPON port.

Table I. Tellabs GPON Equipment

Hardware and Software	**Model or Version**
Chassis (OLT)	1150 MSAP
Modules	
Controller	ESU2A
GPON Module	2x QOIU7A
ONT	8x ONT709
Software	
Software Release	FP25.5.1_013274
Network Manager	Panorama INM 9.3.2.0.5

Router - The uplink(s) from the Tellabs 1150 MSAP need to connect to a router. The router performs several important functions. It allows the GPON users to connect to the rest of the network. It provides routing functions for GPON users who are on different Virtual Local Area Networks (VLANs) on the same Tellabs 1150 MSAP to communicate. Users on the same VLAN who are on the same Tellabs 1150 MSAP will not need a router to communicate if they are using the "Full Bridging" mode of operation on the Tellabs 1150 MSAP. The router used for this testing is the Juniper Networks MX480. It should be noted that because of the low latency of < 10 microseconds and high throughput capacity of the MX480 with a 480 Gbps backplane, the effect on performance is negligible.

Table II. Spirent TestCenter Equipment

Hardware and Software	**Model or Version**
Chassis	SPT-2000A-HS
Modules	2x HyperMetrics CM-1G-D4 (4 Port Gigabit Ethernet)
Software	
Firmware Version	TestCenter 3.71
Test Suite	RFC 2544
Test Duration	60 seconds
Test Protocol Packets	IP Experimental (Protocol = 253)

The test configuration for upstream, downstream, and bidirectional testing is illustrated in Fig. 1.

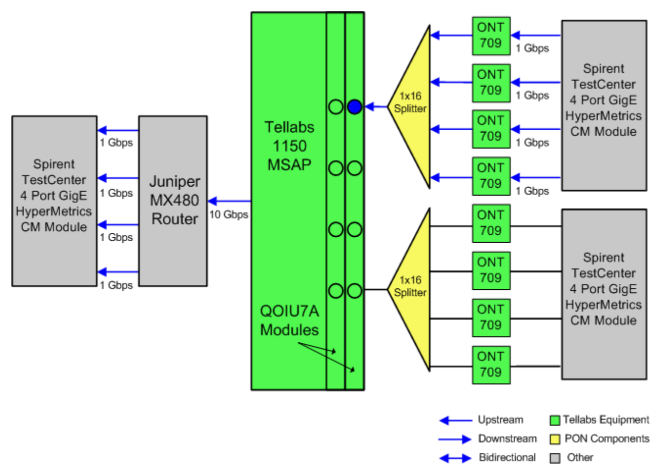

Fig. 1. Spirent TestCenter Configuration

IV. Spirent TestCenter Test Results

The first set of tests were for upstream, downstream, and bidirectional traffic. The direction of the Spirent TestCenter traffic is in the direction of the arrows.

A. Upstream Test Results

Upstream testing involves sending Ethernet frames from the Spirent Ports connected to the ONT709s to the Spirent TestCenter Ports connected to the Juniper MX480 router as shown in Figure 1. The results of upstream testing are presented in Table III.

TABLE II.I UPSTREAM PERFORMANCE RESULTS

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Mean Forwarding Rate (bps)
64	4	248.47	934756891
512	4	258.40	1115783250
1518	4	307.66	1116533131

As is shown in Table III, the Tellabs 1150 MSAP GPON port can support data rates of over 1.11 Gbps in the upstream direction. The *Number of Stream Blocks* column denotes the number of traffic flows from Spirent TestCenter port to Spirent TestCenter port. When 4 Spirent 1 Gbps TestCenter ports are used to send traffic to 4 different Spirent 1 Gbps TestCenter ports, the 4 Gbps aggregate exceeds the GPON port capacity, so a GPON port can be fully tested.

B. Downstream Test Results

Downstream testing involves sending Ethernet frames from the Spirent Ports connected to the Juniper MX480 to the Spirent TestCenter Ports connected to the ONT709s as shown in Fig. 1. The results of downstream testing are presented in Table IV.

Table IV. Downstream Test Results

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Mean Forwarding Rate (bps)
64	4	31.34	1890476045
512	4	49.44	2225563787
1518	4	83.32	2226909959

As is shown in Table IV, the Tellabs 1150 MSAP can support data rates of 2.22 Gbps in the downstream direction.

C. Bidirectional Test Results

The results of bidirectional testing showed no significant difference between the upstream and downstream tests were run independently. Therefore the results are not repeated.

D. GPON Port to GPON Port Test Results

The purpose of these tests is to determine what forwarding rate the Tellabs 1150 MSAP can support between GPON ports that are located on the same and different GPON modules. The results are presented in Tables V and VI. For these tests, the router is not used because an ONT709 that is located on one GPON port sends or receives data from an ONT709 that is located on a different GPON port but is in the same VLAN. The Tellabs 1150 is able to forward this traffic to the correct ONT709. This important to characterize intra VLAN performance.

Table V. Mean Unidirectional Forwarding Rate Performance Results Using the Same GPON Module

Frame Size (bytes)	Number of Streams	Mean Latency (µs)	Mean Forwarding Rate (bps)
64	4	392.16	369044355
512	4	256.27	1088720314
1518	4	306.79	1088777048

Table VI. Mean Unidirectional Forwarding Rate Performance Results Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Mean Forwarding Rate (bps)
64	4	400.29	364759568
512	4	254.92	1034583859
1518	4	360.51	1061018560

As is presented in Tables V and VI, a GPON port on the Tellabs 1150 MSAP can support forwarding rates of over 1000 Mbps when 4 ONT709s are used and the destination ONT709s are located on a GPON port either on the same or on a different GPON module.

By comparing the results in Tables V and VI, it can be observed that there is a slight performance advantage when the GPON ports are on the same GPON module.

E. Single ONT709 Test Resuts

The purpose of these tests is to determine what forwarding rate a single Tellabs ONT709 can support. These tests were performed for upstream, downstream, and bidirectional traffic. The tests were conducted for 1, 2, 3, and 4 ports through a single ONT709. Upstream performance testing was performed first. The configuration for this test is shown in Fig. 2.

The results are shown in Fig. 3. The results show that using additional ports on the ONT709 does not yield additional aggregate bandwidth over using a single port on an ONT709 or a Single Family Unit (SFU) ONT which only has one port.

Downstream performance testing using a single ONT709 was also performed. The configuration for downstream performance testing is the same as Fig. 2 except the test data is going from Tellabs 1150 MSAP to ONT709s. The results are similar to the upstream results and there is no additional aggregate bandwidth by using more the one ONT709 port.

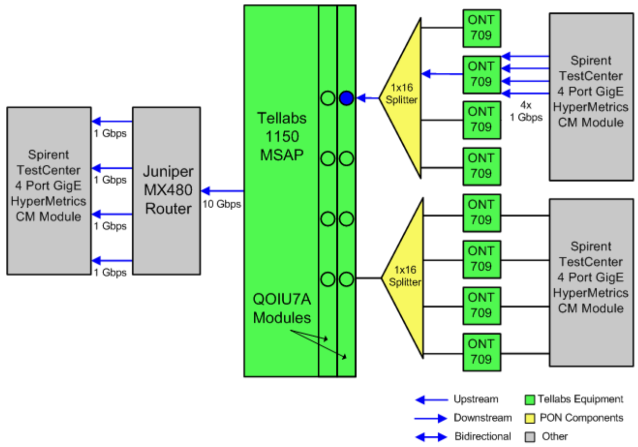

Fig. 2. Configuration for Upstream Performance Testing Using a Single ONT709

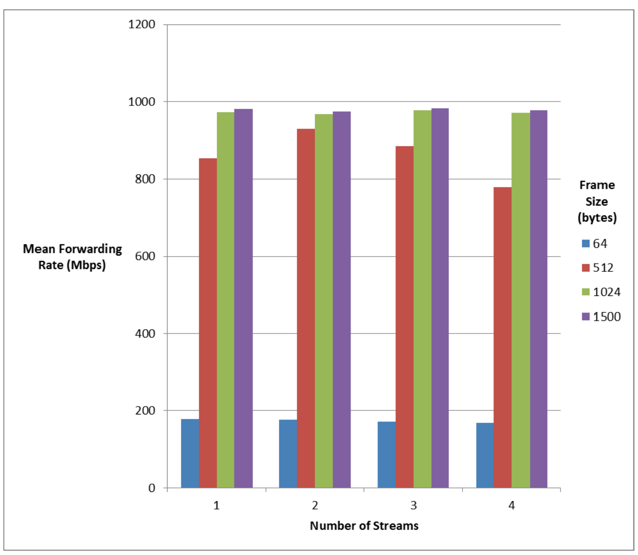

Fig. 3. Mean Upstream Forwarding Rate Performance Results Using a Single ONT709

V. VoIP Testing

Voice Over Internet Protocol (VoIP) is a service which is being deployed over GPON. Under normal uncongested network conditions, packet loss, delay, and jitter are not an issue.

A. Quality of Service for VoIP

Quality of Service (QoS) is very important for VoIP. This is because voice traffic is more sensitive to latency (network delay) and jitter (variation in latency) than web traffic and email. Excessive latency and jitter will cause a poor or unintelligible voice telephone call.

The amount of bandwidth required by a single G.711 mu-law VoIP call is only 64 Kbps for the voice payload. But signaling and transport protocols will require additional bandwidth. If hundreds or thousands of calls are occurring at any one instant, more bandwidth will be required. VoIP performance is negatively impacted in times of competing traffic from heavy network congestion, packet loss, delay, and jitter.

To prioritize VoIP traffic some sort of QoS scheme is needed. The Tellabs 1150 MSAP performs packet marking and prioritization for upstream frames at the ONT709. This is enabled in the Connection Profile for an ONT709 port. Untagged frames arriving at an ONT709 port can be tagged with an 802.1P Class of Service (CoS) Bit priority ranging from 0-7. Should the Type of Service byte in the IP header of the IP packet arriving at an ONT709 port be set with Differentiated Service Code Point (DSCP) bits, the Tellabs 1150 MSAP has the ability to map these DSCP bits into 802.1P CoS Bits. For downstream traffic, the Tellabs 1150 MSAP can be configured to honor and give priority to 802.1P CoS Bits. Higher 802.1P CoS Bit values get higher priority.

B. VoIP Test Strategy

The test strategy used for VoIP is different than the Spirent TestCenter performance tests just discussed. For VoIP testing, the Spirent TestCenter is used to generate competing network traffic. The VoIP telephones are used to call each other, and the voice quality of each call is measured with a Mean Opinion Score (MOS) value by the Prognosis IP Telephone Manager (IPTM) server. The traffic generated by the Spirent TestCenter is varied for upstream, downstream, and bidirectional flows. Then new calls are made and tested for that level of Spirent TestCenter traffic. The tests are divided into two sets. The first set tests without QoS enabled. The tests are then rerun with QoS enabled. The configuration for VoIP testing is illustrated in Fig. 4.

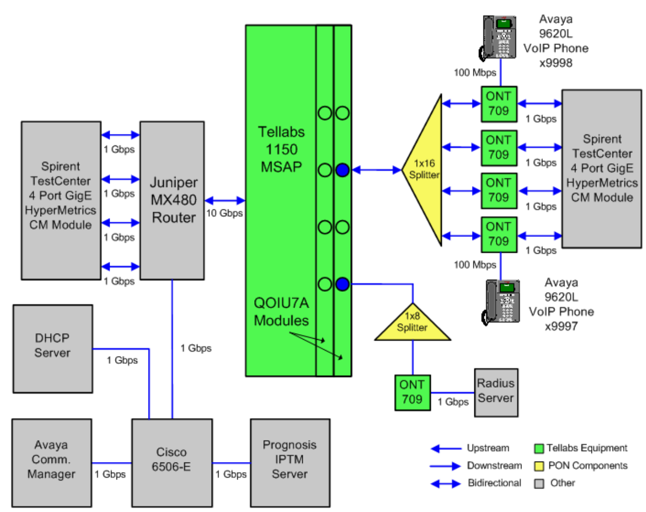

Fig. 4. Configuration for VoIP Testing with Competing Bidirectional Traffic

The actual VoIP hardware and software is listed in Table VII.

Table VII. VoIP Hardware and Software

Hardware and Software	Model or Version
Communication Mgr.	
Server Hardware	2x Avaya S8730
Gateway Hardware	3x Avaya G650
Software	Avaya Version 5.2.1
VoIP Telephone	2x Avaya 9620L
VoIP Signaling Prot.	H.323 Software Version 3.1 with Patch 3.941a
Voice CODEC	G.711 mu-law
Monitoring Software	Prognosis IP Telephony Manager Version 9.6.1

C. *VoIP Performance Test Results*

Tests were performed for upstream, downstream, and bidirectional competing traffic. Because of similar results only the VoIP performance results with 64 byte Ethernet frame competing bidirectional traffic is presented in Table VIII. The MOS value of 4.39 indicates a near perfect telephone call. As is shown, when both the upstream and the downstream have competing traffic rates of 2000 Mbps or greater, MOS values decrease or the call cannot be completed if QoS is not enabled. When QoS is enabled, calls can be completed for all test loads.

Table VIII. VoIP Performance Results with 64 Byte Ethernet Frame Competing Bidirectional Traffic

Traffic Rate Aggregate (Mbps)	MOS X3998 to X3997 No QoS	MOS X3998 to X3997 With QoS	MOS X3997 to X3998 No QoS	MOS X3997 to X3998 With QoS
1200	4.39	4.39	4.39	4.39
2000	2.59	4.39	2.59	4.39
2200	dial tone, no call	4.39	dial tone, no call	4.39
2400	dial tone, no call	3.99	dial tone, no call	3.98
3000	no dial tone	4.39	no dial tone	4.39
4000	no dial tone	4.39	no dial tone	4.39

VI. Streaming Video Testing

The ability to provide streaming video is an important capability of any user network. Streaming video has a variety of informational and instructional. GPON is touted as being capable of providing "triple play" which is voice, video, and data. This section presents the results of the streaming video testing using the Tellabs 1150 MSAP.

A. *Streaming Video Test Configuration*

The test configuration for testing streaming video on the Tellabs 1150 MSAP is shown in Fig. 5. The computer acting as the video server for this test is on the legacy network. The computer acting as the video client is connected to an ONT709. Using the Remote Desktop Protocol (RDP), the video client connects to the video server using the Remote Desktop Connection application. A MPEG video is played on the video server and the video is displayed on the video client. It should be noted that the video server is not on a general user LAN. Also, before applying competing traffic with the Spirent TestCenter, tests were performed under nominal conditions as to assure that there was no other competing traffic or video server usage which would skew the results. The configuration used for these tests are presented in Figure 11.

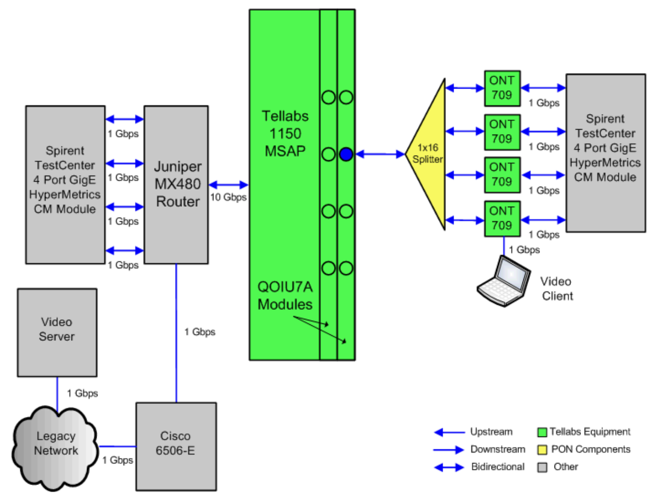

Fig. 5. Configuration for Streaming Video Testing with Competing Bidirectional Traffic

B. *Streaming Video Test Strategy*

For streaming video tests, the Spirent TestCenter was used to generate competing network traffic while an attempt was made to connect to the video server from the video client using the Remote Desktop Connection application. If the connection was successful, the MPEG video is played. The quality of the video displayed on the server was then empirically rated with 1 being very poor and 5 being excellent. The traffic generated by the Spirent TestCenter is varied for upstream, downstream, and bidirectional flows. The tests are divided into two sets. The first set tests without QoS enabled. The tests are then rerun with QoS enabled.

C. *Streaming Video Test Results*

Table IX presents the streaming video quality results with 64 byte Ethernet frame competing bidirectional traffic. As is presented, without QoS enabled, when there is competing bidirectional traffic at rates of 2000 Mbps, a Remote Desktop Connection can either not be completed and maintained or the streaming video quality will be poor.

When QoS is enabled, a Remote Desktop Connection is still possible at 4000 Mbps and perfect streaming video is displayed at any value of competing bidirectional traffic.

Table IX. Streaming Video Quality Results with 64 Byte Ethernet Frame Competing Bidirectional Traffic

Traffic Rate Aggregate (Mbps)	Remote Desktop Conn? No QoS	Video Quality No QoS	Remote Desktop Conn? With QoS	Video Quality With QoS
1200	Yes	5	Yes	5
2000	Yes	1	Yes	5
2200	No	NA	Yes	5
2400	No	NA	Yes	5
3000	No	NA	Yes	5
4000	No	NA	Yes	5

VII. Optimizing GPON Performance

Based on the test results presented in this paper, the following conclusions and recommendations can be made. GPON equipment such as the Tellabs 1150 MSAP can deliver data near the ITU-T G.984 specified 1.244 Gbps upstream and 2.488 Gbps downstream data rates. Traffic flowing upstream does not impact traffic flowing downstream or vice versa. For GPON a typical splitter ratio is 1x32. Putting fewer hosts on a splitter will give each host more available bandwidth. Multiport ONTs, such as a single 4 port ONT, will not provide as much bandwidth as 4 ONTs where only one port is being used. For delay and/or loss sensitive traffic, such as VoIP or streaming video, QoS when enabled works very well in protecting traffic. However, it must be enabled on all networks that will connect to GPON otherwise the QoS markings such as DSCP bits or 802.1 PBits will not be propagated to the GPON equipment.

If there are a lot of large data transfers between machines connected to a single ONT, it would be better to add a small switch to an ONT port. This is because an ONT cannot act as a switch and all traffic must flow to/from the OLT.

A network with heavy peer-to-peer traffic will be limited to the 1.244 Gbps upstream and 2.488 Gbps downstream rates. These networks are better served by a high end access layer switch with a 40 Gbps or more switching capacity. Data centers are also not good candidates for GPON due to high volumes of traffic.

Although not specifically tested for this paper, GPON uses TDMA for the upstream transmission. The ONT receives a time grant from the OLT to transmit. The actual distance between the OLT and ONT is determined by a ranging protocol. For optimum performance, all ONTs on a GPON port or splitter should be approximately the same distance from the splitter, otherwise there will be too much idle time waiting for the data from the more distant ONTs to arrive.

VIII. GPON ENERGY CONSUMPTION TESTING

No performance testing of network gear can be considered complete without testing energy consumption. GPON is touted as a green technology. Therefore, it needed to be tested to determine how it actually performs. Because the OLT and ONTs are separate pieces of equipment, and in different locations, they need to be tested independently.

A. *OLT Energy Consumption*

The energy consumption of an OLT is a factor of the number and type of modules that are inserted into it. Another factor is the method of powering the OLT. If DC power is being used, the efficiency of the rectifier can also affect the total energy consumption. Because rectifier efficiency is beyond the scope of this paper, only OLT energy consumption is discussed. Using a fully loaded Tellabs 1150 MSAP OLT as test equipment, which is powered by a Valere 48 VDC rectifier with 2 V1500A modules, readings from the Valere display were 53.97 Volts and 22 Amperes which is 1187 Watts. The Valere rectifier was rated to be 92% efficient. Therefore the 1150 MSAP used 1187 / 0.92 = 1290 Watts. This reading was observed several times a day and on weekends. It did not change. Therefore OLT energy consumption is based on the OLT and the modules installed in it. It is not dependent upon load.

B. *ONT Energy Consumption*

A similar test was performed on an ONT709. Using a Kill-A-Watt power meter, the energy consumption of an idle ONT 709 was measured to be 6 Watts. The power consumption of an ONT709 was then measured with an aggregate bidirectional test load of 2 Gbps upstream and 2 Gbps downstream 64 byte Ethernet frames equally distributed over 4 ports. The energy consumption changed to 7 Watts, an increase of 16 % for a worse case, nearly impossible load. Under normal loads of 1 Gbps bidirectional traffic, the energy consumption did not change.

C. *Total GPON Energy Consumption*

Based on the energy consumption of the OLT and ONTs, the total energy consumed in a network using GPON will be a function of the OLTs and ONTs. Once powered up, the energy consumption of an OLT or ONT will not change as it would with a server when it is under a heavy load. Also the passive optical splitters will not require any power or cooling as would other access layer network gear would require.

IX. Conclusion

In conclusion, this paper shows that GPON can be a viable energy saving access layer technology. When properly designed and configured, It can provide an end user better performance than many copper-based legacy technologies such as DSL.

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